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Asbestos Fiber Reentrainment during Vacuuming and Wet-Cleaning of Carpet at a Captive Research Site

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16. ABSTRACT

A statistical evaluation was made of airborne asbestos concentrations measured before, during, and after removal of asbestos-containing fireproofing at three university buildings. Of the three sites studied, all passed the AHERA Z-test when the work area asbestos levels were compared to perimeter levels (outside the abatement area but inside the building). Two sites also passed the Z-test when work area and outdoor air levels were compared. At one site, contamination of the perimeter area occurred at some point during the abatement project. Had this area been used in the Z-test clearance comparison, a contaminated site would have been falsely released.

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ASBESTOS FIBER REENTRAINMENT DURING VACUUMING AND WET-CLEANING OF CARPET AT A CAPTIVE RESEARCH SITE

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Asbestos Fiber Reentrainment During Vacuuming and Wet-Cleaning of Carpet at a Captive Research Site

ABSTRACT

A study was conducted to compare the effectiveness of alternative carpet cleaning techniques and to evaluate the potential for asbestos fiber reentrainment during cleaning of carpet contaminated with asbestos. The equipment was evaluated at two carpet contamination levels. Airborne asbestos concentrations were determined before and during carpet cleaning. Overall, airborne asbestos concentrations were two to four times greater during the carpet cleaning activity. The level of asbestos contamination and the type of cleaning method had no statistically significant effect on the relative increase of airborne asbestos concentrations during carpet cleaning.

INTRODUCTION

Buildings that contain friable asbestos-containing materials (ACM) may present unique exposure problems for custodial workers. A major concern is the extent which carpet and furnishings may be reservoirs of asbestos fibers, and their subsequent behavior when normal custodial cleaning operations are performed.

The U. S. Environmental Protection Agency (EPA) performed a series of controlled experiments at a captive research site to 1) evaluate two cleaning methods for removal of asbestos fibers from carpet, and 2) evaluate the potential for asbestos-fiber reentrainment during these cleaning activities. Analysis of the carpet samples to evaluate the removal effectiveness of the cleaning methods is ongoing and will be reported in the future. This paper presents the airborne asbestos concentrations resulting from the dry-vacuuming and wet-cleaning of asbestos-contaminated carpet.

EXPERIMENTAL DESIGN

This study was conducted at a captive research site consisting of an unoccupied building scheduled for demolition. Two rooms, each with approximately 600 square feet of floor space, were constructed in a larger bay of the building.

A layout drawing of the test facility is shown in Figure 1. The rooms were constructed of 2 x 4-inch lumber with studs spaced on 24-inch centers, and 3/4-inch plywood floors. The ceiling, floor, and walls were double-covered with 6-mil polyethylene sheeting. (The interior layer of polyethylene sheeting was encapsulated and replaced after each experiment). Separate decontamination facilities for workers and waste-materials were

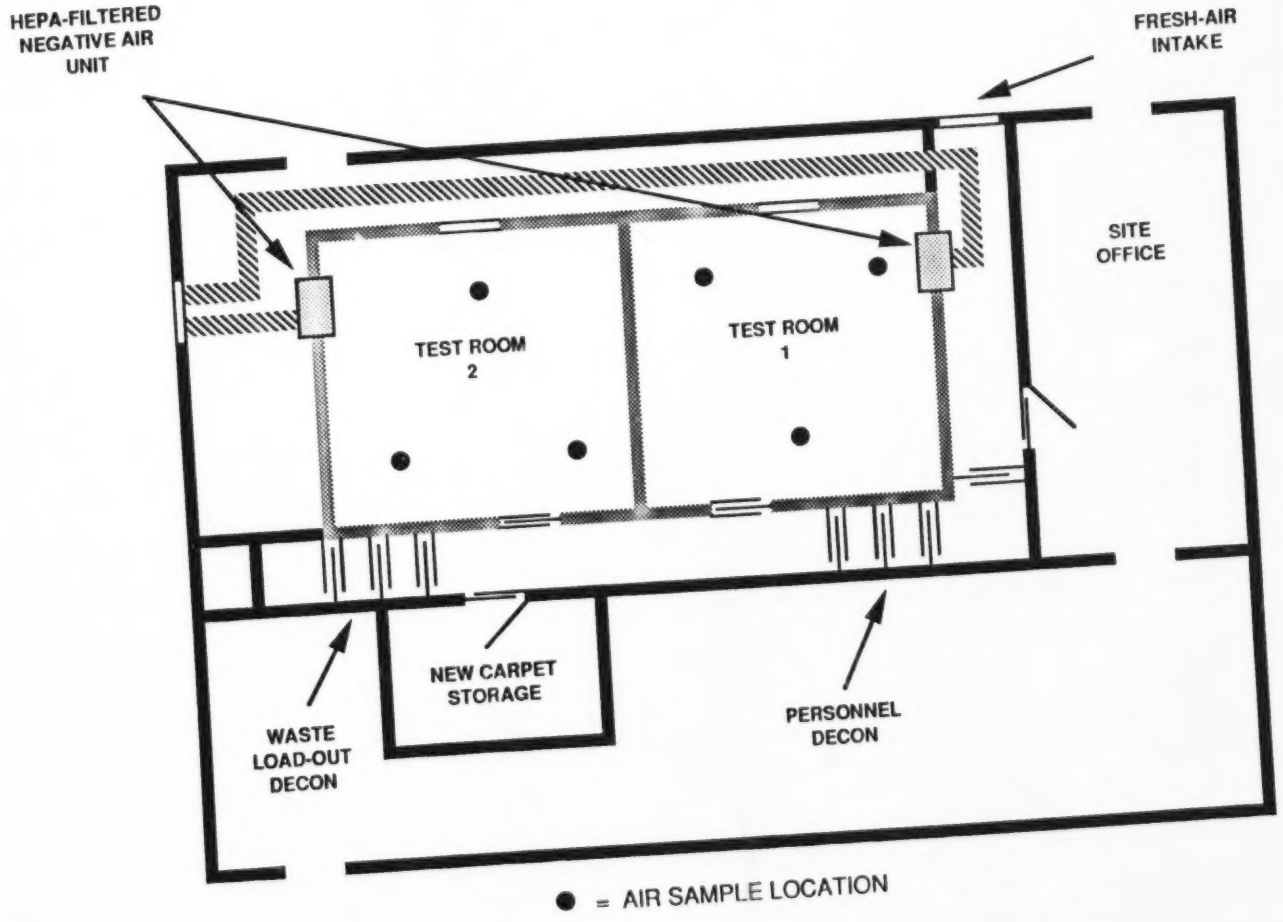

Figure 1. Layout of test facility, bldg. 1422-A.

connected to the experimental areas. Room size was determined based on the minimum amount of time required to vacuum or wet-clean the room and attain an adequate sample air volume to achieve a specified analytical sensitivity. A 52-inch ceiling-mounted, axial flow, propeller fan was installed in each room to facilitate air movement and minimize temperature stratification.

Two carpet cleaning techniques (HEPA-filtered dry vacuuming and HEPA-filtered hot water extraction) were used on carpet artificially contaminated with 100 million and 1 billion asbestos structures per square foot (a.s./ft^2). Each treatment combination was replicated four times to yield a total of 16 experiments. Each type of cleaning equipment was tested in each room the same number of times for each contamination level. A single experiment included contaminating a new piece of carpet in a previously cleaned room, collecting work area air samples, vacuuming or wet-cleaning the carpet for a specified period of time while simultaneously collecting work area air samples, removing the carpet, and cleaning the room.

Three work area air samples were collected before cleaning and three air samples were collected during carpet cleaning for each experiment. The air samplers were positioned in a triangular pattern (Figure 1) at a height of approximately five feet above the floor.

Carpet Selection

A survey of fourteen General Service Administration (GSA) field offices in eleven different states distributed across the United States was conducted to determine the specific type and manufacturer of carpet to be used in the study. Eight offices indicated a preference for the same manufacturer and variety of carpet. The carpet selected was first-grade, 100-percent Nylon, with 0.25-inch cut pile, 28 ounces of yarn per square foot, and dual reenforced vinyl backing. The carpet was manufactured in roll sizes of 54 by 90 feet.

Cleaning Equipment

The same GSA field office survey identified a commonly used HEPA-filtered vacuum cleaner. Four different HEPA-filtered vacuum cleaners of the same model were used in this study. These units were equipped with a motor driven carpet nozzle with a rotating brush. The hot water extraction unit used was selected based on the results of a survey of six trade associations for commercial cleaners. Four different cleaners of the same model were used. These units were equipped with an extractor tool which uses a motor-driven cylindrical brush to agitate and scrub the carpet during the extraction process.

Sampling Methodology

Air samples were collected on open-face 25-mm diameter, 0.45-um pore-size mixed cellulose ester membrane filters with a 5-um pore-size, mixed cellulose ester backup diffusing filter and cellulose ester support pad contained in a three piece cassette. The filter cassettes were positioned approximately 5 feet above the floor with the filter face at approximately a 45-degree angle toward the floor. The filter assembly was attached to an electric-powered vacuum pump operating at a flow rate of 10 liters per minute. Air samples were collected for a minimum of 65 minutes before and during carpet cleaning to achieve a minimum air volume of approximately 650 liters. The sampling pumps were calibrated both before and after sampling.

Analytical Methodology

The mixed cellulose ester filters were analyzed by Transmission Electron Microscopy (TEM). These filters were prepared and analyzed in accordance with the nonmandatory TEM method as described in the Asbestos Hazard Emergency Response Act (AHERA) final rule (52 CFR 41821). Because there are no OSHA Permissible Exposure Limits or NIOSH Recommended Exposure Limits for airborne asbestos measured by TEM, a subset of filters were selected for additional analysis by phase contrast microscopy (PCM) according to NIOSH Method 7400.

Carpet Contamination

Carpet contamination levels for this study were selected based on field data reported by Wilmoth et. al.[1] Wilmoth reported that carpet samples from an occupied building were collected using two different sampling techniques. Microvacuuming of the contaminated carpet revealed asbestos levels ranging from approximately 8000 to 2 billion a.s./ft^2. Bulk sample sonification of the samples showed asbestos levels ranging from 30 million to 4 billion a.s./ft^2. These results indicate that the experimental contamination levels of 100 million and 1 billion a.s./ft^2 represent realistic carpet contamination levels.

The carpet was contaminated with a spray-applied dispersion of asbestos in distilled water. Sealed ampules of asbestos fiber dispersions were prepared such that the contents of one ampule, dispersed in approximately 6 liters of freshly-distilled water, would provide the required concentration of suspension to artificially contaminate one 600 ft^2 sample of carpet.

The original suspension was prepared by dispersing a known weight of chrysotile in freshly-distilled water. A weight of 409.5 mg of purified Calidria chrysotile was placed in an agate mortar and, using a pestle, was lightly ground with a small volume of water, gradually adding more freshly-distilled water

until a creamy liquid was obtained. This liquid was made up to 400 mL in a polypropylene disposable beaker then placed in an ultrasonic bath for approximately 30 minutes. The suspension was then made up to 1500 mL with distilled water in a one-gallon polyethylene bottle. The bottle was then placed in an ultrasonic bath for 30 minutes, during which time the bottle was removed and shaken vigorously. For the lower concentration, a volume of 150 mL of this suspension was made up to 1500 mL with freshly-distilled water in another one-gallon polyethylene bottle. The two suspensions had concentrations of 273 mg/liter and 27.3 mg/liter, respectively. A volume of 50 mL of suspension was used to prepare each ampule.

The asbestos dispersion was applied to the carpet using a meticulously cleaned hand-pumped garden sprayer. A fixed number of pumps were used for each batch to provide consistent spray pressure. The desired controlled spray was experimentally determined by trial and error prior to beginning the tests with asbestos. The pressure was kept within the desired range by adding a fixed number of pump strokes after each fixed area was sprayed in a predetermined pattern following a grid work of string placed over the carpet before starting each experiment. The tank was periodically shaken and agitated to aid in keeping the asbestos fibers suspended in the tank. Dehumidifiers were placed in the room overnight to aid in drying the carpet. The following day a 200-pound steel lawn roller was rolled over the carpet surfaces to simulate the effects of normal foot traffic in working the asbestos into the carpet.

Prior to the start of the field experiments, the spray-applied dispersion was evaluated in the laboratory to examine the effectiveness of the technique to apply the asbestos dispersion and define the degree of fiber loss, if any. An asbestos dispersion was prepared in a hand-pumped sprayer identical to that used in the field experiments. Three one-liter samples were then collected by spraying the asbestos dispersion into separate glass containers. These samples were then analyzed to determine the asbestos concentration in terms of fibers per liter of water. These results are presented in Table 1. The original dispersion concentration was approximately (2 to 4) x 10^{13} asbestos fibers per liter of water. These results indicate no significant loss of fibers during the transfer of the liquid-dispersion through the sprayer's hose and nozzle.

TABLE 1. RESULTS FROM PRELIMINARY STUDY OF SPRAY-APPLIED ASBESTOS DISPERSION

Volume in Sprayer at Time of Sample Collection (Liters)	Sample Volume (Liters)	Mean Asbestos Concentration (Fibers/Liter)
6	1	2.38×10^{13}
4	1	2.22×10^{13}
2	1	2.20×10^{13}

Cleaning Technique

The carpet was vacuumed or wet-cleaned for a period of approximately 65 minutes to allow the collection of air samples of sufficient volume to obtain an analytical sensitivity of 0.005 asbestos structures per cubic centimeter. The carpet was cleaned in two directions, the second at a 90-degree angle to the first.

Quality Assurance

Specific quality assurance procedures used to ensure the accuracy and precision of the collection and TEM analysis of air samples included the use of filter lot blanks, laboratory blanks, field blanks, replicate and duplicate sample analyses.

Filter lot blanks are unused filters selected at random and analyzed to determine the background contamination level of asbestos. One hundred (100) lot blanks were submitted for TEM analysis. No asbestos structures were detected in 1000 grid openings analyzed. The lot of filters was subsequently considered acceptable for use.

During the setup of the air sampling pumps, pre-loaded filter cassettes were selected as field blanks. These filters were labeled and handled in a manner similar to that for the actual sample filters, but they were never attached to the pump. One field blank was collected for each of the 16 experiments. Two of the 16 filters each contained one asbestos structure. Additionally, prior to each of the sixteen experiments, one sample cassette was selected from the filter inventory to be used as a laboratory blank. These samples were sealed and submitted for use by the analytical laboratory to ensure that there was no blank interferences during the analytical procedures. Two of the

16 sealed blanks each contained two asbestos structures. Analysis of the field and laboratory blanks demonstrated filter contamination was significantly below the guideline of 3 asbestos structures average per 10 grid openings.

Duplicate sample analysis provides a means of quantifying intralaboratory precision and refers to the analysis of the same grid preparation by a second microscopist. Five samples were randomly selected for duplicate analysis. There was no evidence of inconsistency among the two sets of analyses. A paired t-test[2] did not detect any statistically significant tendency for one analyst to give higher or lower structure counts ($p=0.6195$).

Replicate sample analysis provides a means of quantifying analytical variability introduced by the filter preparation procedure and refers to the analysis of a second grid preparation from the original filter, but not necessarily by the same analyst. Five samples were randomly selected for replicate analysis. While a paired t-test did detect a statistically significant tendency for the replicate analysis to yield lower asbestos concentrations ($p=0.0259$), the effect due to the filter preparation procedure is confounded by the effect of a second analyst. Hence, an overall statement regarding analytical reproducibility is not appropriate.

Statistical Analysis

Methods--

Airborne asbestos concentrations were determined before and during carpet cleaning to study the effect of cleaning method and contamination loading on fiber reentrainment during carpet cleaning. Three work area samples were collected before and during carpet cleaning for each experiment. A single estimate of the airborne asbestos concentration before and during cleaning was then determined by averaging the three respective work area samples. As a measure of relative change in airborne asbestos concentration, the ratio of the concentration during cleaning to the concentration prior to cleaning was computed. The natural log of this ratio was then analyzed using a two factor analysis of variance[2] (ANOVA) with cleaning method and contamination level as the main effects. The two-factor interaction term was also included in the model.

Summary statistics (arithmetic mean and standard deviation) were calculated according to cleaning method and contamination level.

RESULTS AND DISCUSSION

Figure 2 presents the average airborne asbestos concentrations measured before and during cleaning for each cleaning method and carpet contamination loading. Table 2 presents the summary statistics.

Air sampling results from two of the sixteen experiments showed that for both wet cleaning and HEPA vacuuming, the average airborne asbestos concentrations decreased during carpet cleaning The explanation for this anomaly is that the HEPA filtration system used to ventilate the test rooms was operating during the carpet cleaning phase of these two experiments. Therefore, these results were omitted from the statistical analysis of the data.

Results from the two factor ANOVA indicated no statistically significant difference between cleaning methods with respect to fiber reentrainment during carpet cleaning ($p=0.5847$). That is, the mean relative increase in airborne asbestos concentrations during carpet cleaning with a HEPA vacuum was not significantly different from that found during wet cleaning. When averaged across both contamination loadings, airborne asbestos concentrations increased approximately 2.6 times during HEPA vacuuming and approximately 3.2 times during wet cleaning.

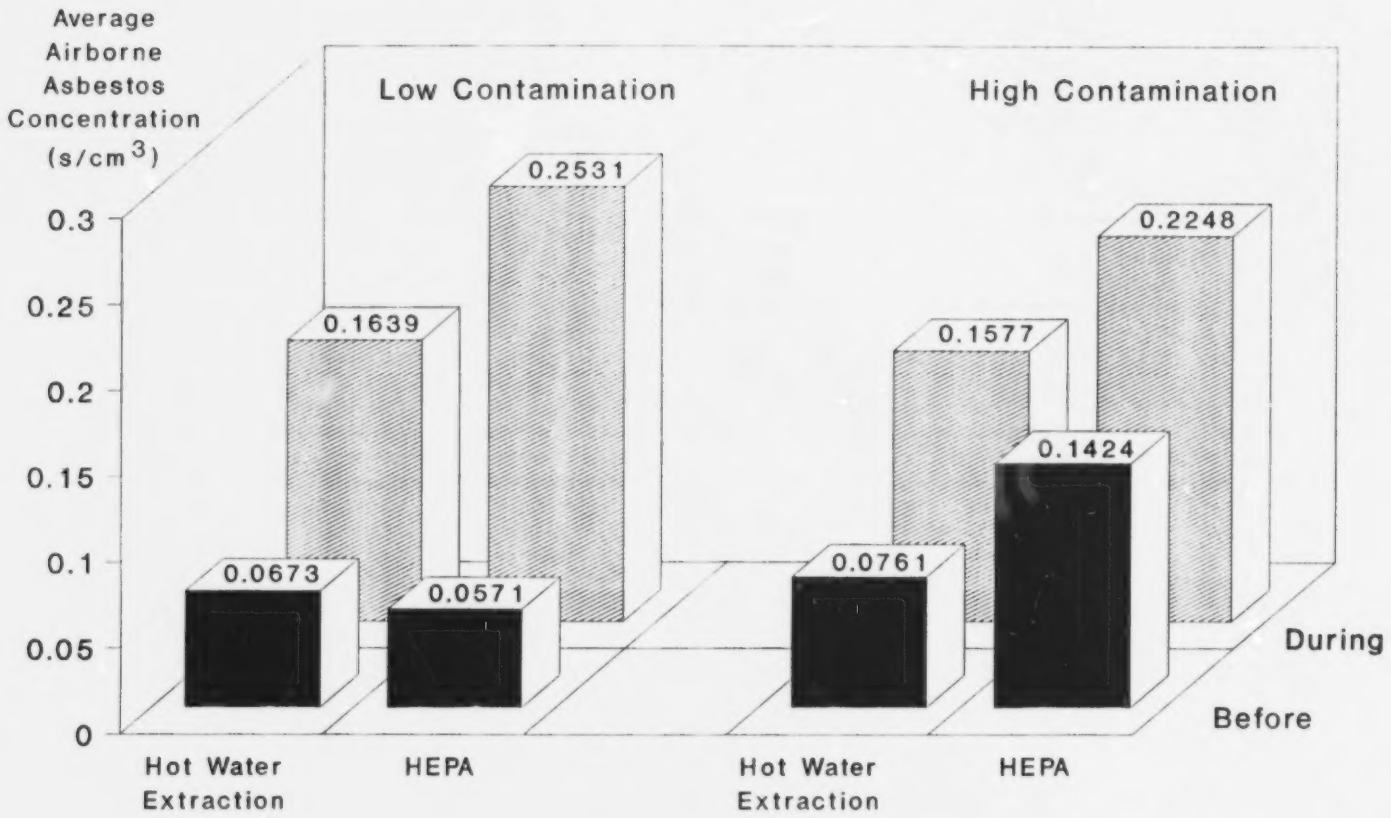

Figure 2. Average airborne asbestos concentrations before and during carpet cleaning.

TABLE 2. SUMMARY STATISTICS FOR AIRBORNE ASBESTOS CONCENTRATIONS BEFORE AND DURING CARPET CLEANING.

Approximate Contamination Loading (a.s./ft^2)	Cleaner	Number of Samples	Airborne Asbestos Concentration (s/cm^3) Average	Standard Deviation
		Before Cleaning		
100 million	Extraction	9	0.0673	0.0947
	HEPA-Vacuum	9	0.0571	0.0300
		During Cleaning		
	Extraction	9	0.1639	0.1020
	HEPA-Vacuum	9	0.2531	0.1729
		Before Cleaning		
1 Billion	Extraction	16	0.0761	0.0425
	HEPA-Vacuum	16	0.1424	0.1340
		During Cleaning		
	Extraction	16	0.1577	0.0602
	HEPA-Vacuum	16	0.2248	0.1114

Note: The data points used in the calculation of each summary statistic are the averages of the three work area samples before and during cleaning.

Similarly, no statistically significant difference between carpet contamination loadings with respect to fiber reentrainment was evident ($p=0.0857$). That is, the mean relative increase in airborne asbestos concentrations during carpet cleaning when the carpet contamination level was 100 million a.s./ft^2 was not significantly different from that found when the carpet contamination loading was 1 billion a.s./ft^2. When averaged across both cleaning methods, airborne asbestos concentrations increased approximately 2.5 times at the high contamination level and approximately 5 times at the low contamination level.

Given that no differences due to cleaning method or contamination level were detectable, the question of whether there was an overall increase in mean airborne asbestos concentration during carpet cleaning was tested. ANOVA results indicate that, overall, the mean airborne asbestos concentration during carpet cleaning was significantly higher during carpet cleaning than that just prior to cleaning ($p=0.0001$). Specifically, the mean airborne asbestos concentration was between 2 and 4 times greater during carpet cleaning.

Airborne Asbestos Fiber Distribution

TEM analysis of the 47 work area samples before and during cleaning yielded a total of 2,839 structures. Of these, 2757 (97.1%) were chrysotile, 8 (0.3%) were amphibole, and 74 (2.6%) were ambiguous. The structure morphology distribution is summarized in Table 3.

TABLE 3. STRUCTURE MORPHOLOGY DISTRIBUTION OF AIR SAMPLES COLLECTED BEFORE AND DURING CARPET CLEANING.

Structure Type	Number of Bundles	Number of Clusters	Number of Fibers	Number of Matrices
Chrysotile	30	7	2661	59
Amphibole	0	2	5	1
Ambiguous	2	0	70	2

These data indicate that the original chrysotile fibers used to prepare the asbestos dispersion remained intact as fibers. That is, there appeared to be no significant tendency for the fibers to clump together as a result of the dispersion preparation, carpet contamination, or cleaning technique.

The presence of amphibole asbestos fibers in the air is probably due to existing conditions prior to experimentation. Pre-study air monitoring identified three amphibole asbestos fibers in seven air samples collected.

The structure length distribution of asbestos particles found in the air before and during carpet cleaning is summarized in Table 4 and illustrated in Figure 3. Eighty-four percent (84%) of the chrysotile structures identified were one micron or less in length. Only nine particles were identified with lengths greater than five microns. Compared to the fiber length distribution of chrysotile used to contaminate the carpet (see Figure 4), these data certainly suggest that the larger asbestos particles either remained in the carpet or were prevented from escaping into the air by the carpet cleaning activity.

Samples Analyzed by PCM

Twelve samples were selected to be analyzed by phase contrast microscopy based on their respective high asbestos concentrations determined by TEM. Results from both TEM and PCM analyses are compared Table 5. Airborne fiber concentrations determined by PCM were significantly lower than the corresponding asbestos concentrations determined by TEM. This difference is presumably due to the limitation of PCM to detect small fibers. It should be noted that the majority of asbestos fibers applied (Figure 4) did not meet the dimensional criteria (length >5 um) of NIOSH Method 7400 and hence were not counted.

TABLE 4. FIBER LENGTH DISTRIBUTION OF AIRBORNE ASBESTOS IN THE WORK AREA BEFORE AND DURING CARPET CLEANING

Structure Length (Micrometers)	Number of Structures(%)		
	Before Cleaning	During Cleaning	
		Extraction	HEPA-Vacuum
0.5 to 1.0	866(83.7)	710(82.0)	731(85.3)
1.0 to 2.0	138(13.3)	132(15.2)	110(12.8)
2.0 to 3.0	22 (2.1)	11 (1.3)	9 (1.1)
3.0 to 4.0	5 (0.5)	7 (0.8)	3 (0.4)
4.0 to 5.0	2 (0.2)	1 (0.1)	1 (0.1)
5.0 to 6.0	1 (0.1)	1 (0.1)	2 (0.2)
6.0 to 7.0	0 (0.0)	2 (0.2)	1 (0.1)
7.0 to 8.0	0 (0.0)	1 (0.1)	0 (0.0)
8.0 to 9.0	0 (0.0)	0 (0.0)	0 (0.0)
9.0 to 10.0	0 (0.0)	0 (0.0)	0 (0.0)
> 10	1 (0.1)	1 (0.1)	0 (0.0)

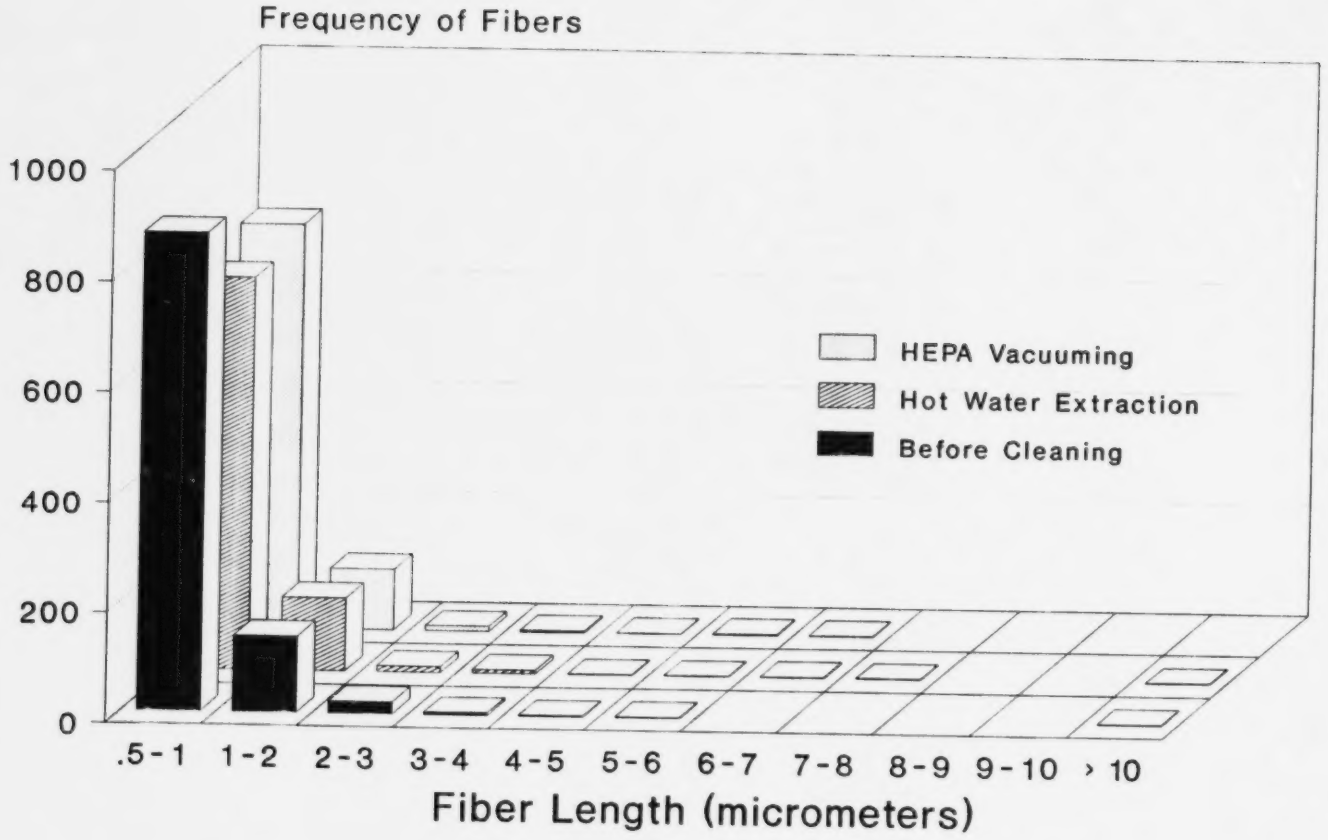

Figure 3. Fiber length distribution for airborne asbestos before and during carpet cleaning.

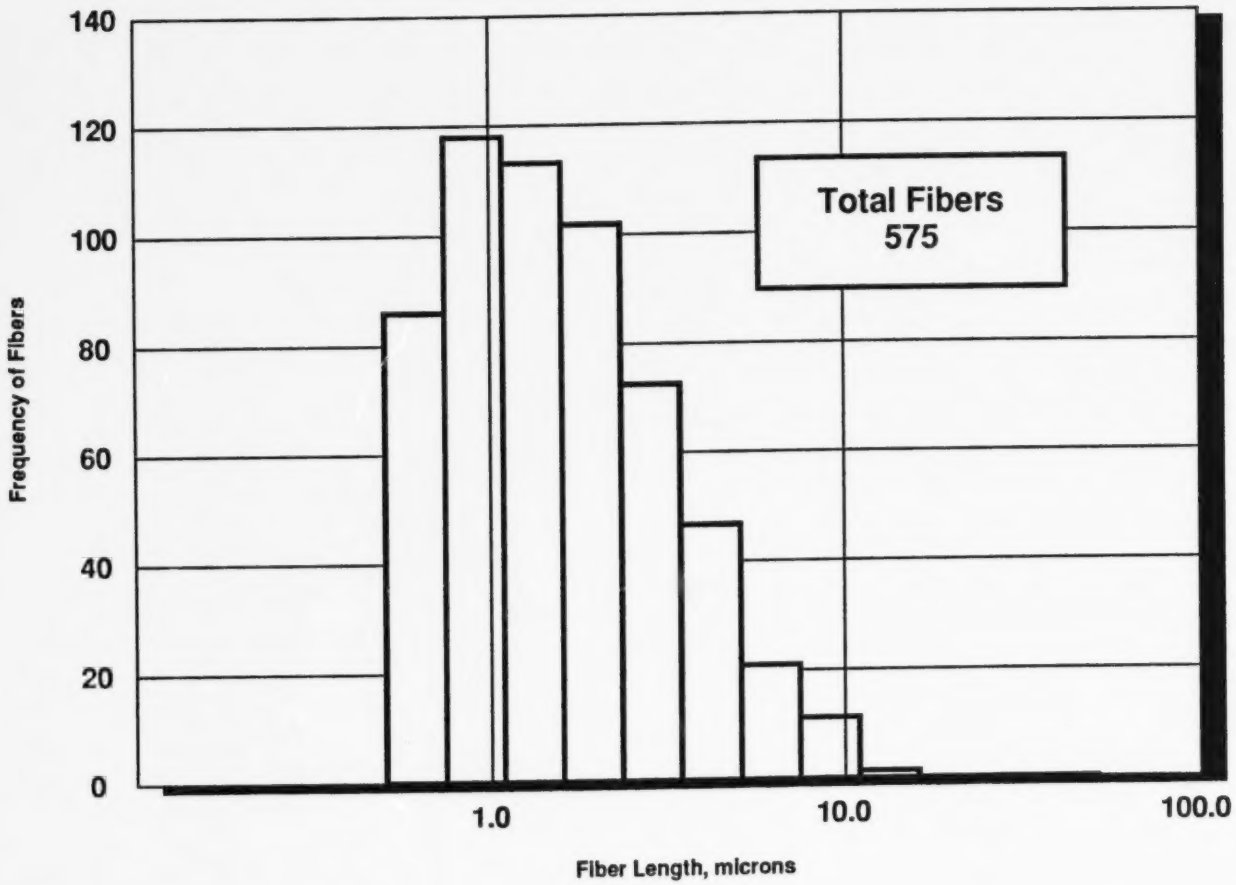

Figure 4. Distribution of chrysotile fiber lengths in the aqueous asbestos dispersion.

TABLE 5. COMPARISON OF TEM AND PCM ANALYSES OF SELECTED AIR SAMPLES

Sample Number	PCM Fiber Concentration (f/cm^3)	TEM Asbestos Concentration (s/cm^3)
03-A457D	0.0035	0.5507
03-A458D	0.0023	0.3658
03-A459D	0.0081	0.3464
10-A496B	0.0026	0.3656
10-A497B	0.0078	0.2909
10-A498B	0.0068	0.3375
10-A499D	0.0116	0.3871
10-A500D	0.0109	0.4891
10-A501D	0	0.0070
14-A523D	0.0061	0.3177
14-A524D	0.0138	0.3779
14-A525D	0.0138	0.3368

CONCLUSIONS

Dry-vacuuming and wet-cleaning of carpet artificially contaminated with asbestos fibers resulted in a statistically significant increase in airborne asbestos concentrations. The increase did not vary significantly with type of cleaning method (wet or dry) or with the two levels of asbestos contamination applied to the carpet.

Although this study suggests that performing normal custodial cleaning of asbestos contaminated carpet may result in elevated airborne concentrations, these data should not be directly extrapolated to real-world situations. Further research is required to determine the actual exposure risk to custodial workers performing these activities in buildings containing friable asbestos containing materials.

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